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INTRODUCTION

For a number of years the NACA flight-research laboratory has been using a standard procedure for evaluating the aileron characteristics of airplanes. The purpose of this paper is to describe the NACA procedure and to offer pertinent suggestions that may be of value to others interested in the conduct of such tests.

VARIABLES MEASURED

The aileron characteristics are determined by measuring the following variables during flight:

(1) Rolling velocity

(2) Aileron positions

(3) Aileron stick force or tangential wheel force

(4) Indicated airspeed

(5) Altitude

(6) Free-air temperature

(7) Rudder position (optional)

Rolling Velocity

The rolling velocity to be measured in the procedure outlined herein is the maximum following a given abrupt deflection of the ailerons at a given speed. Although an instrument from which a time history of the rolling velocity throughout the test maneuver can be obtained is most desirable, any instrument capable of measuring only maximum angular velocities about the X airplane axis is normally adequate in using the standard NACA procedure. (The axes referred to herein are the body axes of an airplane.) Rolling velocity may be satisfactorily measured by instruments utilizing the gyroscopic effect for response. In the NACA rolling-velocity recorder a small flywheel is rotated at constant speed about its own axis, which is alined with the Z airplane axis when the instrument is installed in an airplane. The flywheel is totally restrained about the X axis and will always roll with the airplane. During rolling, the precessional torque on the flywheel shaft acting about the Y axis deflects a torsional spring supporting the flywheel frame and this deflection is photographically recorded through a mechanical-optical arrangement. Another method for measuring rolling velocity consists in photographing an artificial horizon and a clock reading to 0.01 second with a motion-picture camera running at fairly high speed. If the speed regulation of the camera is good, the camera may be used for establishing the time scale and the clock may be omitted. The resulting record of angle of bank plotted against time is differentiated to determine the maximum rolling velocity. Another method for measuring rolling velocity consists in photographing the actual horizon during test maneuvers.

Aileron Positions

The aileron positions to be measured are those at trim and those at the deflection used to produce a given abrupt roll. Control-position recorders should be located in the airplane wings as close to each aileron as possible and should be connected to the ailerons by independent systems for transmitting motion. This installation eliminates the errors due to play or flexibility in the control system that may be incurred if the instrument is connected to a cable, tube, or cockpit wheel or stick control. Stretch in the control system can be corrected for only if the separate hinge moments on the ailerons are known - a condition not ordinarily achieved in flight tests as it is generally much easier simply to measure the over-all force supplied to the aileron control system by the pilot. If the afore-mentioned installation cannot be used, errors due to control flexibility may be estimated from static loading tests, wind-tunnel tests, and calculations. In some cases aileron positions may be de-

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termined by means of motion-picture cameras set to photograph the ailerons. It is to be noted that errors due to flexibility of the control system are avoided by this method also.

Aileron Control Force

The aileron stick or wheel force to be measured is the force required to hold a given aileron deflection at or near the time of maximum rolling velocity in a given roll. Force recorders or indicators from which only the maximum force that occurred during a maneuver can be obtained are unsatisfactory because the force required to deflect the ailerons abruptly almost always exceeds the steady force required to hold the ailerons deflected on account of control-system inertia. In most NACA flight tests forces are recorded by an automatically recording instrument synchronized with the rolling-velocity recorder. When this system is not used, however, it has been found that good results may be obtained by using a force indicator held between the pilot's hand and the stick or wheel. The pilot (or observer) reads the indicated force required to hold the control deflected. Errors encountered in the indicator method are fairly small, because the aileron hinge moments remain essentially constant as long as the rolling velocity is near its maximum value.

Indicated Airspeed

Indicated airspeed may be obtained by automatically recording a measure of the difference between the static and the total pressures developed by a pitot-static installation or by simply reading the pilot's airspeed meter an instant before a test roll is initiated. In either case, it is desirable to correct the reading for pitot-static-position error and instrument-scale error.

Altitude

Altitude is measured primarily for the purpose of determining static pressure in order that the indicated airspeed can be converted to true airspeed. Although a recording altimeter may be used, it is generally sufficient to read the pilot's altimeter immediately before the roll is made.

Free-Air Temperature

Free-air temperature is also measured primarily for the purpose of converting indicated to true airspeed. Indicating instruments are nearly always used and their readings are corrected for the adiabatic temperature rise in some manner that depends on the type of instrument employed. If the aileron rolls are made during dives, the area and altitude range covered should be surveyed to establish free-air temperatures immediately before or after the tests are made.

Rudder Position

Rudder position is measured only to check on the correctness of the piloting technique. For this reason, no great effort need be made in the interests of exactness. If the pilot is experienced in the technique involved, the measurement of rudder position may be dispensed with.

FLIGHT PROCEDURE

Lateral-Control Tests

The NACA flight procedure for testing lateral control may be described in step-by-step form as follows:

1. Pilot trims all control forces to zero in straight, laterally level flight at a predetermined indicated airspeed.

2. Pilot very abruptly moves the aileron control to a predetermined deflection set by a control stop while holding the rudder fixed in its trim position. Five separate aileron deflections in each direction are ordinarily sufficient at a given airspeed; these deflections are 1/4, 1/2, 3/4, 7/8, and full at all speeds at which full deflection is permissible. At higher speeds, the foregoing deflections are reduced in proportion to the reduction in maximum allowable aileron deflection. For fighter-type airplanes, it is usual to test the ailerons at several speeds ranging from slightly above the stall to about 80 percent of the permissible diving speed. For bombers, the upper limit should be somewhat above maximum level-flight speed. In the landing condition (flaps and gear down), speeds are selected to cover the permissible speed range.

3. Pilot allows roll to progress until after maximum rolling velocity has been reached without further movement of any control.

4. Pilot recovers from maneuver in any desired manner.

5. Pilot repeats procedure after resetting the stop for the aileron control system until all required deflections to both right and left have been performed at the same indicated airspeed.

Recommendations and comments regarding the flight technique used in the NACA procedure follow:

Trimming all control forces to zero, though highly desirable, is not an absolute necessity. When the capabilities of the trimming device permit, the aileron control force should invariably be trimmed to zero before rolls are made.

Unless otherwise specified, the rolls should be started from a power-for-level-flight condition, as this condition is most desirable from the pilot's standpoint. At speeds above maximum level-flight speed, normal rated power is generally used.

Unless the altitude is otherwise specified, it is recommended that an altitude of 10,000 feet be used for rolls started from level flight because this altitude has been frequently chosen for comparing rolling velocities measured with different airplanes. In making the tests, however, first consideration should be given to the smoothness of the air at various altitudes.

As a matter of interest, results of NACA flight tests show that an abrupt control deflection corresponds to moving the ailerons from trim to full deflection in about 0.1 to 0.2 second.

In fixing aileron deflection, a simple method consists in using a chain extending from the top of the control stick or the back of a hand force indicator to an open hook fastened in the side of the pilot's compartment; the links of this chain are marked to give various predetermined aileron deflections. For wheel controls, some method equally simple can probably be found. It is important that provision be made for almost instantaneous removal of the limiting device at the pilot's will. If breaking of the chain will result in dangerous control deflections, it is advisable to use an additional absolute stop for limiting the greatest permissible deflection. Whenever a method for limiting control deflection is installed, due regard must be shown for the location of the force-measuring device. The force recorder or indicator must respond only to hinge moments transmitted from the ailerons except in the case of full aileron deflection - that is, against permament stop in airplane. In this case the measurement of force is often dispensed with in the interests of simplicity.

The importance of holding the rudder in its trim position during the test maneuver should be emphasized. If the pilot is allowed to affect the roll by application of rudder control, the test results tend to become meaningless.

Maximum rolling velocity generally occurs very shortly after the ailerons reach their given deflection from trim.

Aileron Trim Changes with Speed

Tests of aileron characteristics should include a measurement of aileron trim changes with speed for straight laterally level flight conditions. These measurements are made by simply trimming the aileron control force to zero at level-flight speed with rated power with the airplane in the clean configuration and then measuring the aileron stick force and aileron angles required to trim the airplane in laterally level straight flight at various other speeds throughout the speed range, both with rated power and with power off.

EVALUATION OF LATERAL-CONTROL DATA

The initial step in evaluating the data consists in reducing the flight measurements to the following quantities for each roll:

(1) Maximum rolling velocity attained p_{max}, radians per second.

(2) Total aileron deflection used δ_{a_T}, degrees.

This quantity is the sum of the up and down aileron deflections from trim.

(3) Aileron stick force at normal stick grip position or tangential wheel force at rim of wheel F_a, pounds. This quantity is the difference between the force at trim, which should be zero, and the force required to hold the controls deflected in a given roll.

(4) Correct indicated airspeed V_i, miles per hour. This item should be defined (see reference 1) because no definition for the term is universally accepted at the present time.

(5) True airspeed V, feet per second.

The second step consists in calculating the maximum helix angle $pb/2V$ generated by the wing tip of the airplane during each roll. In the term $pb/2V$, b is the wing span in feet and p and V are as defined in items (1) and (5), respectively.

Finally, the data are plotted with stick force and $pb/2V$ as ordinates against change in total aileron angle as the common abscissa. Data are segregated by using different symbols for different indicated airspeeds. This plot, together with a knowledge of the wing span, almost completely defines the aileron characteristics of the airplane because $pb/2V$ is independent of altitude and aileron stick forces are essentially dependent on the indicated airspeed if effects of compressibility are neglected.

Another plot of interest, particularly when comparisons are made between various airplanes, is a graph in which total aileron angle, rolling velocity at a standard altitude of 10,000 feet, and $pb/2V$ are plotted against indicated airspeed for a set value of control force (30 and/or 50 lb for stick controls or 80 lb for wheel controls).

GENERAL SUGGESTIONS

Aileron Strength Limitations

In most airplanes previously tested it has been found that safe aileron deflections have been automatically insured by high aileron control forces. With modern high-speed airplanes having highly balanced ailerons or booster-type controls, however, the possibility of breaking the ailerons or permanently deforming the wing structure is greatly increased - particularly in lateral control tests when a pilot may attempt to obtain a specified deflection of the ailerons regardless of accompanying control forces.

For these reasons it is recommended that before completely outlining a test program an analysis of aileron and wing strength be made and deflection limits be established for use as a guide in planning tests. Results of such an analysis may be plotted as maximum allowable aileron deflections against indicated airspeed at test altitude.

Aileron Interference Effects

The configuration of the wings of the airplane during routine aileron tests should be maintained as closely as possible to the normal service configuration. During recent NACA flight tests with one airplane, it was found that mounting a special airspeed boom forward of one aileron had a perceptible effect on aileron effectiveness and a relatively larger effect on aileron stick forces. Even small modifications to the surface smoothness of the wing, such as tapering off sharp edges of a painted insignia, gave well-defined changes in stick-force characteristics. With these considerations in mind, therefore, care should be exercised in mounting test equipment in order that interference effects will be minimized or nonexistent.

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REFERENCE

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